# CHAPTER 7. ENERGY USE ANALYSIS

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# CHAPTER 7. ENERGY USE ANALYSIS

## 7.1 INTRODUCTION

An energy use analysis is generally carried out for appliance standards rulemakings to calculate the energy consumption of the equipment in question. For commercial refrigeration equipment, the U.S. Department of Energy (DOE) calculated the energy consumption of the equipment as part of the engineering analysis (see technical support document (TSD) chapter 5) using an energy consumption model. During the analysis for the 2009 final rule for commercial refrigeration equipment (74 FR 1092 (Jan. 9 2009)), DOE conducted an energy use analysis for certain remote condensing equipment and concluded that the results agree reasonably well with those calculated by the energy consumption model used in the engineering analysis. Even though self-contained and remote condensing equipment differ with respect to their compressor and condenser configurations, the equipment load calculations, which include conduction, radiation and infiltration loads, and loads from the electrical components, are similar for both types of equipment. Therefore, for the current rulemaking, DOE retained the 2009 final rule analysis conclusions and used the engineering analysis energy consumption model calculations of equipment energy consumption values for life-cycle cost and payback period analysis (TSD chapter 8) and national impact analysis (TSD chapter 10).

The current rulemaking covers a larger proportion of self-contained commercial refrigeration equipment than the 2009 final rule analysis. Self-contained equipment may have a greater impact on the building's heating, ventilation, and air-conditioning (HVAC) loads because, unlike the display cases connected to a remote condensing unit, self-contained equipment rejects heat inside the building. DOE evaluated the effect of efficiency improvements in self-contained equipment on the building HVAC loads by simulating a self-contained freezer in restaurant buildings. The energy use analysis presented in this chapter was not used in the preliminary analysis of the current rulemaking and is presented here for information only.

## 7.2 WHOLE-BUILDING ANNUAL ENERGY SIMULATIONS FOR SELF-CONTAINED EQUIPMENT

DOE used a whole-building simulation tool, EnergyPlus, to model the effect of self-contained commercial refrigeration units on building heating and cooling loads. EnergyPlus is the primary software tool supported by DOE's Building Technologies Program for energy use analysis of buildings.

Self-contained commercial refrigeration equipment absorbs some heat from the building space, but then rejects this same heat back into the surrounding space along with additional heat equal in value to the compressor energy consumption and the heat generated by the other direct electricity consuming components of the refrigeration equipment, such as lights, evaporator fans, defrost system, and anti-sweat heaters. In other words, all the electrical energy consumed by the refrigeration equipment manifests itself in the form of additional heat that is exhausted into the building's conditioned space. Therefore, one simple method to analyze the effect of self-contained commercial refrigeration equipment on the building heating and cooling loads is to model the equipment as an added heat source in the building. The heat input into the building is equal to the energy consumed by the equipment. However, such an approach will not allow the model to properly account for the impact of latent loads, defrost power requirements, and periods of high loads (for example, when doors are opened frequently). For this exercise, DOE chose to model the self-contained refrigeration equipment in detail. Equipment design characteristics came from the engineering analysis. DOE used American National Standards Institute (ANSI)/Air-Conditioning and Refrigeration Institute (ARI) Standard 1200-2006 (ARI 1200-2006)[1] test procedure for guidance for certain features such as door-opening schedule.

The self-contained commercial refrigeration equipment was modeled in EnergyPlus in three parts: (1) evaporator; (2) compressor; and (3) condenser. The heat load from the refrigerated case was the input to the evaporator. The heat extracted by the evaporator was transferred as a heat load on the compressor. The total heat output from the compressor, which has compressor energy in addition to the heat removed from the refrigerated case, was rejected to the ambient air through the condenser.

The heat load on the refrigerated case is the sum of various heat sources, including conduction and radiation heat transfer into the case, infiltration of ambient air into the case, and heat electrical components such as lights, fans, defrost system, and anti-sweat heaters. Conduction heat transfer into the case is calculated based on the insulation properties (conductivity) of the walls and doors, difference in case internal temperature and the ambient temperature, and the area of the walls and doors. Radiation heat transfer is calculated in association with conduction by appropriately increasing the value of conductivity of the transparent doors. Infiltration load is divided into two parts—sensible heat load (due to difference between the temperature of ambient air and the case operating temperature) and latent heat load (due to condensation of excess moisture in the ambient air). Latent heat load is a function of the difference in relative humidity between the ambient air and the air inside the refrigerated case. The rate of infiltration of air into the refrigerated case (expressed in pounds of air per hour) was obtained from the engineering analysis. The model specifies the door-opening schedule in the simulations and the frequency and duration of door openings consistent with the ARI 1200-2006 test procedure specifications. Heat input to the refrigerated case from the electrical components is calculated in EnergyPlus by multiplying the run time of the components by their respective power ratings. The EnergyPlus model calculates the heat load appropriately according to the run time of the components.

Compressor capacity and power curves, which were used in the engineering analysis, were provided as model inputs. Rated saturated condenser temperature (SCT) and saturated evaporator temperature (SET) were specified to initially define the compressor design operating conditions. Actual SCT and SET depended on the case heat load in a particular time step and were calculated by the model at each time step based on the load during each time step and the load history over the previous time steps. The actual SCT and SET values were then used with the capacity and power equations to determine the compressor capacity and power consumption during each time step.

Inputs to define condenser and evaporator performance included effectiveness factors (UA values) and rated power of the fans. The condenser heat was rejected to the ambient air.

Self-contained refrigerators and freezers are typically used in small business establishments like restaurants and convenience stores. DOE selected restaurants as a suitable building type for the whole-building energy use simulations with self-contained equipment. DOE carried out simulations in both quick-service and full-service restaurant models. EnergyPlus is capable of simulating various building types that are based on the DOE reference models which can be accessed at http://www1.eere.energy.gov/buildings/commercial_initiative/reference_buildings.html. Both the DOE restaurant reference models are divided into two zones: cooking and dining. DOE carried out separate simulations to study the impact of refrigerators and freezers placed in each zone.

Typically, in a quick-service restaurant, there is no distinct separation between the cooking and the dining zones. The ventilation and subsequent cooling or heating of the cooking zone is achieved by the transfer of conditioned air from the dining zone to the cooking zone. DOE reference models for both the quick-service and full-service restaurants have a feature where conditioned air was transferred from the dining zone to the cooking zone. However, in a typical full-service restaurant, the dining zone and the cooking zone are separated by physical barriers, with separate heating and cooling units for each area. DOE modified the full-service restaurant to use separate heating and cooling units for the cooking and dining zones. The modification involved eliminating the air transfer from the dining to the cooking zone and adding a make-up air unit to supply conditioned air to the cooking zone.

DOE conducted the simulation of each building in 15 climate zones across the United States. For each climate zone, a typical city was chosen to represent the weather. For each building type, each climate zone was assigned a weighting factor, which represents the percentage of the entire U.S. population of buildings represented by this building type that occur within that climate zone.[2,3] The weighting factors were applied to the simulation results to calculate aggregated national-weighted average values. For each climate region identified, a characteristic city is used as representative climate for the region as shown in Table 7.2.1. The EnergyPlus analyses were conducted using TMY2 weather data for each of these representative cities. HVAC system types, system efficiencies, and envelope insulation levels for these reference buildings were specified according to American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 90.1-2004.[4]

**Table 7.2.1 Representative Cities and Weighting Factors for 15 Climate Zones**

| Climate Zone | Typical City | Weighting Factor Quick-Service Restaurant | Weighting Factor Full-Service Restaurant |
|---|---|---|---|
| Zone 1A | Miami, FL | 1.33% | 1.37% |
| Zone 2A | Houston, TX | 3.46% | 3.72% |
| Zone 2B | Phoenix, AZ | 15.62% | 16.00% |
| Zone 3A | Memphis, TN | 10.77% | 7.19% |
| Zone 3B | El Paso, TX | 1.18% | 0.87% |
| Zone 3C | San Francisco, CA | 17.35% | 16.86% |
| Zone 4A | Baltimore, MD | 0.91% | 0.88% |
| Zone 4B | Albuquerque, NM | 2.44% | 1.55% |
| Zone 4C | Salem, OR | 15.17% | 19.27% |
| Zone 5A | Chicago, IL | 4.37% | 4.71% |
| Zone 5B | Boise, ID | 21.90% | 21.68% |
| Zone 6A | Burlington, VT | 0.53% | 0.61% |
| Zone 6B | Helena, MT | 4.32% | 4.70% |
| Zone 7 | Duluth, MN | 0.61% | 0.56% |
| Zone 8 | Fairbanks, AK | 0.04% | 0.02% |

Whole-building simulations in these restaurant buildings included modeling of a freezer belonging to the VCT.SC.L equipment class (self-contained vertical freezer with transparent doors). The baseline energy consumption of the VCT.SC.L equipment class is among the highest of all the self-contained commercial refrigeration equipment classes. The refrigeration model used the same case size and design specifications that were used in modeling as a representative unit for the engineering analysis. Simulations were carried out using four design option levels: AD1 (baseline), AD3, AD7, and AD13 (see TSD chapter 5 for list of design option levels for VCT.SC.L equipment class). The following section presents the results of the simulations by comparing the whole-building energy use values from the simulations with AD3, AD7 and AD13 against the whole-building energy use of the baseline level (AD1) simulation.

## 7.3 WHOLE-BUILDING ENERGY USE SIMULATIONS RESULTS

The energy consumption of the VCT.SC.L freezer at AD1 represented about 3 percent of the total electric energy consumption of the quick-service restaurant and 2 percent in the case of full-service restaurant. Table 7.3.1 presents a summary of the simulations results. Results are presented in the form of the difference in energy consumption values by comparing the simulation results with the AD1 level against the simulations results with AD3, AD7, and AD13. “Refrigeration savings,” expressed in kilowatt-hours per day (kWh/day), are the differences in energy consumption of an AD1 freezer when compared to the three higher efficiency freezer designs. “Heating savings,” expressed in therms per day (therms/day), are the differences in gas usage (for building space heating purposes) of the building in the case of AD1 freezer simulations as compared to the higher efficiency equipment simulations. Similarly, “Cooling savings,” expressed in kilowatt-hours per day, are the differences in electricity consumption, for building space cooling purposes. Positive values imply that the energy or gas usage is lower in the case of simulations with a higher-efficiency freezer compared to the simulation with baseline freezer. To facilitate comparison, the savings values were also expressed in the form of energy cost savings in dollars per day ($/day), by using an electricity price of 0.0939 $/kWh and gas price of 1.2201 $/therm. “Heating + Cooling Savings” are the sum of heating savings and cooling savings expressed in dollars per day. The last column of the table presents the heating + cooling savings as a fraction of refrigeration savings, expressed in the form of percentages.

When the refrigeration equipment simulated was located in the dining area of the restaurants, the overall impact of improvements in refrigeration equipment efficiency was a small increase (shown in Table 7.3.1 as negative overall savings) in the building heating and cooling costs, equivalent to 2 to 4 percent of the refrigeration cost savings. When the simulations were carried out with refrigeration equipment in the cooking zone of a full-service restaurant, the overall impact of improving the refrigeration equipment efficiency was a small increase in building heating and cooling costs, equivalent to 4 to 5 percent of the refrigeration cost savings. When the simulations were carried out with refrigeration equipment in the cooking zone of a quick-service restaurant, the overall impact of improving the refrigeration equipment efficiency was a reduction in overall building heating and cooling energy costs, equivalent to 14 to15 percent of the refrigeration cost savings.

**Table 7.3.1 Whole Building Analysis Results (National Average) for VCT.SC.L Freezer in Fast-Food and Full-Service Restaurants**

| *Restaurant* | *Restaurant* | *Refrigeration* | *Heating Savings* | *Cooling Savings* | *Heating + Cooling* |
|---|---|---|---|---|---|

| *Type* | *Zone* | *Savings* | | | | | | *Savings* | |
|---|---|---|---|---|---|---|---|---|---|
| | | *kWh/day* | *$/day** | *therms/day* | *$/day** | *kWh/day* | *$/day** | *$/day** | *percent of refrigeration savings†* |
| **Savings from replacing AD1 with AD3** | | | | | | | | | |
| **Fast Food** | **Dining** | 3.35 | 0.31 | -0.04 | (0.05) | 0.47 | 0.04 | (0.01) | -2% |
| | **Cooking** | 3.39 | 0.32 | 0.01 | 0.01 | 0.40 | 0.04 | 0.05 | 15% |
| **Full-Service** | **Dining** | 3.30 | 0.31 | -0.04 | (0.05) | 0.46 | 0.04 | (0.01) | -2% |
| | **Cooking** | 3.31 | 0.31 | -0.05 | (0.06) | 0.54 | 0.05 | (0.01) | -4% |
| **Savings from replacing AD1 with AD7** | | | | | | | | | |
| **Fast Food** | **Dining** | 13.79 | 1.29 | -0.20 | (0.24) | 1.94 | 0.18 | (0.06) | -4% |
| | **Cooking** | 13.90 | 1.31 | 0.03 | 0.03 | 1.59 | 0.15 | 0.18 | 14% |
| **Full-Service** | **Dining** | 13.71 | 1.29 | -0.19 | (0.23) | 1.95 | 0.18 | (0.05) | -4% |
| | **Cooking** | 13.76 | $ 1.29 | -0.22 | (0.27) | 2.15 | 0.20 | (0.07) | -5% |
| **Savings from replacing AD1 with AD13** | | | | | | | | | |
| **Fast Food** | **Dining** | 16.37 | 1.54 | -0.22 | (0.26) | 2.20 | 0.21 | (0.06) | -4% |
| | **Cooking** | 16.53 | 1.55 | 0.04 | 0.04 | 1.85 | 0.17 | 0.22 | 14% |
| **Full-Service** | **Dining** | 16.29 | 1.53 | -0.21 | (0.26) | 2.22 | 0.21 | (0.05) | -4% |
| | **Cooking** | 16.28 | 1.53 | -0.26 | (0.32) | 2.52 | 0.24 | (0.08) | -5% |

* Electricity price: 0.0939 $/kWh; gas price: 1.2201 $/therm.
†These values were obtained by dividing the sum of heating and cooling savings by the refrigeration savings (expressed as a percentage).

## 7.4 SUMMARY AND CONCLUSIONS

DOE carried out whole-building energy consumption simulations to understand the impact of efficiency improvements in self-contained refrigeration equipment on building heating and cooling loads. Simulations were carried out with a representative freezer belonging to the VCT.SC.L equipment class and DOE reference models for full-service and quick-service restaurants. Simulations were carried out in both the cooking and dining zones of the restaurants. Gas consumption for building heating, and electricity consumption for the VCT.SC.L freezer and building cooling, were converted into energy costs to facilitate comparison of the three values.

Overall, the net impact of improved refrigeration equipment efficiency on the building heating and cooling loads resulted in a small average increase in total building heating and cooling costs, on the order of 2 to 5 percent of the refrigeration cost savings in most of the cases examined. Considering the uncertainties involved in the actual field operations of the equipment and the assumptions involved in characterizing typical restaurant models, this negative 2 to 5 percent impact can be considered negligible.

One exception where the impact of equipment efficiency improvement on the building heating and cooling costs was relatively high was for cases where the refrigeration equipment was placed in the cooking zone of quick-service restaurant. The cooking zone in the DOE reference building model for quick-service restaurants was serviced by transfer of conditioned air from the dining zone. The impact was found to be in the form of building heating and cooling cost savings on the order of 15 percent of the direct refrigeration cost savings, primarily from reduction in cooling energy used in the cooking zone. In most cases, display-type equipment, such as VCT.SC.L freezer, is used for merchandising purposes and is located in customer-frequented areas, which are similar to the dining zones of the restaurants. Based on the results, the impact of improving the efficiency of equipment used in dining areas will generally be a very slight increase in space conditioning costs, relative to the direct refrigeration savings. The impact of improving the efficiency of refrigeration equipment used primarily in restaurant cooking zones is more mixed and will be dependent on the ventilation strategy of the cooking zones with the HVAC impact, according to this analysis between additional HVAC costs at about 5 percent of the direct refrigeration savings to additional savings as much as 15 percent of the direct refrigeration savings. Given the difficulty in establishing ventilation practices and, in particular, the amount of transfer air from dining zone to cooling zones in restaurants, DOE considers these impacts to be small and difficult to further quantify.

Refrigerators and freezers with solid doors are used for storage and are typically located in the cooking zones of the restaurants, where simulations (with a VCT.SC.L freezer) indicate overall savings in the building heating and cooling costs in the cases where the cooking zones are serviced by transfer of conditioned air from dining zone. It is difficult to ascertain the prevalence of such practices (transfer air from dining to cooking zones) in the restaurant industry, particularly for the existing building market. The total energy consumption of the storage-type equipment is generally less than display-type equipment for comparable refrigeration units (see TSD chapter 8). Therefore, the net impact on building heating and cooling costs of storage-type equipment is smaller compared to display-type equipment. Further, while an overwhelming majority of self-contained storage type equipment is used in restaurants, the energy consumption of a typical refrigerator or freezer is less than 3 percent of the total building energy consumption. Given that the savings potential for an individual refrigerator is a fraction of its total energy use and that any corresponding heating and cooling impact is a small fraction of the direct refrigeration savings (when considered on a national basis), the overall impact of efficiency improvement in self-contained storage-type equipment on the restaurant heating and cooling loads is believed to be insignificant.

Based on the energy use analysis results, DOE concludes that the impact of efficiency improvements in self-contained equipment on building heating and cooling loads is negligible.

## REFERENCES


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